APPENDIX A

HYDROLOGY

PREPARED BY

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

HYDROLOGY

INITIAL LAKEBELT MODELING RESULTS

PART I REGIONAL MODELING STUDY

Purpose

This report provides a summary of the regional modeling studies conducted by the staff of the South Florida Water Management District for evaluating the first four scenarios/alternatives associated with the Northwest Dade County Freshwater Lake Plan This regional modeling is designed to address the hydrologic impacts/benefits of the first four scenarios that include varying degrees of rock mining in the Lake Belt region The results of this preliminary analysis should assist the committee and other working groups in designing the future scenarios/alternatives

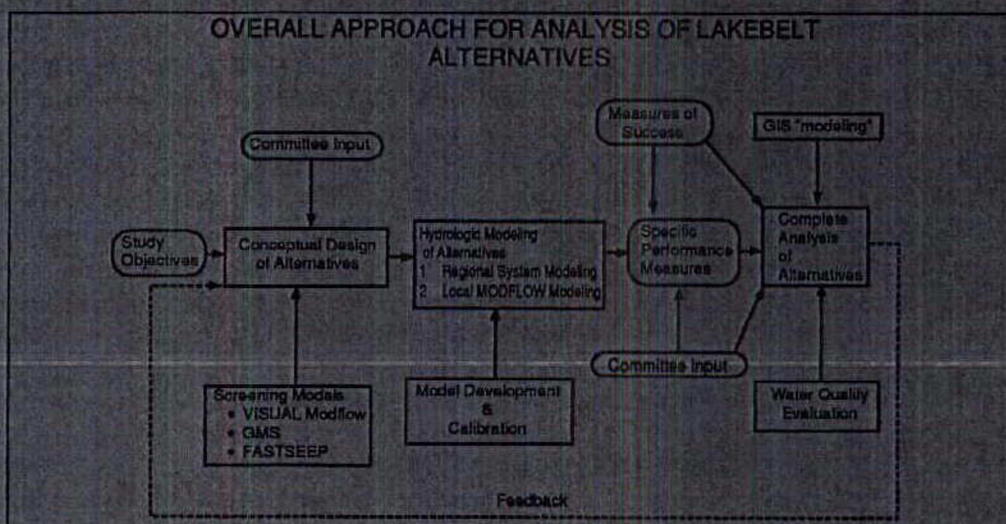

Figure 1 Overall approach for Analysis of Alternatives presented at the April, 1996 Committee Meeting

Brief Review

The overall approach for the Analysis of Lake Belt alternatives was presented at the April 1996 Committee meeting, and it is shown in the figure 1

Using the input from the Lake Belt Committee and various other working groups, the initial conceptual design of scenarios and alternatives was completed During this phase, the design tools (screening models) such as Visual MODFLOW, to develop the so-called "strip models" in an attempt to understand relative effects of hydrologic processes within the Lake Belt region While these screening level models, if applied properly, are

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useful for initial design purposes, they are inadequate for comprehensive evaluation of Lake Belt alternatives.

Since June 1995, the District staff of the Planning Department has focused much of their attention on developing comprehensive models necessary for analyzing the complex scenarios and alternatives identified by the committee and the working groups. These models are:

a. South Florida Water Management Model Version 2.8 (SFWMM)

This is the regional system model that has been used extensively by SFWMD in projects involving regional-scale issues. Much of the developmental efforts including its calibration and enhancement have been done for the Lower East Coast Regional Water Supply Plan (LEC Plan). The model simulates the important hydrologic process in South Florida on a 2 mile x 2 mile mesh that covers a region spanning from Lake Okeechobee to Florida Bay including the entire Lower East Coast. The simulation period for the SFWMM is 1965-1990 and the primary time step is 1-day although some processes such as sheet flow uses a shorter time step of 6-hours. This model is considered as the best available modeling tool of its scale to

investigate regional scale water management scenarios/alternatives.

b. Lake Belt MODFLOW Model Version 1.2

This model was specifically developed for analyzing Lake Belt scenarios and alternatives and it includes the entire region in and around Lake Belt. Part of the western boundary of the model corresponds to L-67 levees in WCA-3B whereas the eastern model boundary is at the Atlantic Ocean. The northern boundary of the model is C-11 canal and the southern boundary is as far south as C-1 canal in Dade County. The resolution of the model is 1000 ft. x 1000 ft. and includes 7-layers encompassing the entire surficial aquifer in the region. The model uses an extensive spatial database to define the hydrogeologic and other characteristics of the Lake Belt region. This geographic database is part of the ARC/INFO Geographical Information System (GIS) which is used for developing the input data sets for the MODFLOW model.

The initial calibration of the model has used a wetter period of 1993-94, where calibration is nearly complete through 1993. The model can be executed both in "steady state" (constant inputs and boundary conditions) and in "transient state" (time varying inputs and boundary conditions).

The purpose of this report is to present the results of the regional modeling simulations. The results of the MODFLOW model simulations will be presented in a separate document. The work to date also includes the development of specific Measures of Success or Performance Measures (Appendix I) for comparing Lake Belt Alternatives with respect to project objectives It should be noted that the current modeling studies can only address hydrologic issues associated with the project Specifically, the quantitative measures of success generated from the model runs will address the hydrologic issues associated with the following objectives

a Enhance Water Supply for Dade County and the Everglades
b Protect the Environment

Plans are being made to preliminarily evaluate the water quality concerns of different alternatives It is expected that the hydrologic modeling results generated from this work will provide the basis for future work on water quality concerns The hydrologic modeling results can also provide useful information for evaluating alternatives with respect to biological aspects of local and regional wetlands, estuaries (Biscayne Bay and Florida Bay), and the littoral areas around the proposed lakes

Strengths and Limitations of the Selected Modeling Approach

The regional simulation model (SFWMM) was selected to estimate regional impacts/benefits that would result from the implementation of various structural and non-structural alternatives within the Lake Belt region The scale of the regional model (2 mile x 2 mile) must be considered in evaluating its modeling results Its strength, as with most models, is primarily in demonstrating the incremental differences between successive alternatives The regional model will be particularly useful for evaluating regional-scale hydrologic effects of structural changes within the study area such as backpumping and seepage control To a more limited extent, the model should also be useful for demonstrating the trends and relative changes resulting from the nonstructural alternatives such as various scenarios of rock mining within the Lake Belt region There is no other appropriate tool available to investigate regional effects of Lake Belt alternatives

For the initial modeling studies reported here, the selected approach is to first look at the results of the regional model to investigate the trend and relative differences in the first group of "non-structural" scenarios with varying extent of rock mining The analysis of the different scenarios will be repeated by using the MODFLOW model In the final analysis, the MODFLOW model will be used to determine the specific quantitative effects of various rock mining scenarios and other alternatives that will be modeled in the future It is clear that both models are necessary to address the questions being asked regarding the impacts/benefits of various alternatives

Alternative Scenarios Identified for Regional Modeling-SFWMM

The six (6) scenarios included in this analysis are essentially, "non-structural" alternatives that simply address increasing extent of mining in the Lake Belt region (Table 1) The results presented in this document address only these scenarios Alternatives 5, 6 and 7 will be addressed in a later study

In particular, two of the scenarios (a and b) have been created for the alternatives 3 and 4 each These reflect the variations of alternatives 3 and 4 with respect to "1990 base condition" and the "2010 base condition" used for the Lower East Coast Regional Water Supply Plan (LEC Plan) development efforts In general, they are two "snapshots" of system-wide landuse and associated structures and their operations, which are used to evaluate the performance of changes within the Lake Belt region For this reason, care should be taken when comparing modeling results of different scenarios In presenting modeling results, the alternatives 1, 2, 3a, and 4a will be lumped into a single group as they represent the same "snapshot" Alternatives 3b and 4b correspond to the 2010 "snapshot"

The modeling and analysis of the first group of scenarios can help address the following key question

- *What are the regional and local hydrologic impacts/benefits due to increasing the extent of lakes created by rock mining?*

Table 1. Initial Scenarios/alternatives identified for modeling

Scenario/ Alternative Number	Description
1	No lakes(pre rock-mining scenario)
2	Generalized Existing Conditions (present condition)
3	Generalized Permitted Lakes 3a. Under "1990 base" conditions 3b. Under "2010 base" conditions
4	Proposed Rock Miners Initial Plan 4a. Under "1990 base" conditions 4b. Under "2010 base" conditions
5	Lower East Coast Regional Water Supply Plan Alternative 2 (horse-shoe curtain wall in Lake Belt)
6	The "Bath-Tub" (LECRWSP Alternative 4)
7	FPL Strip (Above ground storage area-LECRWSP Alt 5A)

* Shaded rows identify the scenarios selected for initial modeling

Possible Hydrologic Effects of Creating Large Lakes

There are many hydrologic changes that can occur due to creation of extensive lakes within the Lake Belt region They include, <u>but are not limited to</u>, the following

1 Change/no change in seepage loss from WCA-3B (negative / no effect)

2 Possible increase in storage space (within the range of water table variation) that would be beneficial to water supply (positive)
3 Increase/decrease in evapotranspiration losses (negative/positive)
4 Possible increase in rainfall-recharge within lake areas (positive)

Key Assumptions Used For Regional Modeling

The key modeling assumptions used for the regional simulation model (SFWMM) are shown in Table 2

For the regional modeling in this study, assumptions were made to reflect a particular condition or snapshot being simulated For convenience, the same version of the model developed to simulate the "1990 base condition" of the Lower East Coast Water Supply Plan (LEC Plan) was used for alternatives 1, 2, 3a, and 4a This version of the model simulates the 1965-1990 hydrology and the operational rules of the more recent period, which are assumed to be static during the entire period of simulation The "1990 base" version of SFWMM actually uses 1988 landcover data However, the 1994 landuse map (EAS Associates, 1994) available for Lake Belt region was used to reflect more realistic "present conditions" within the Lake Belt study area

For alternatives 3b and 4b, the "2010 base condition" of the LECRWSP was used This snapshot assumes the implementation of such regional projects as Kissimmee River Restoration, C-111 GRR, Everglades Construction Project including STAs, and Modified Water Deliveries to the Everglades National Park (ENP) It also uses the projected landuse for the year 2010 and the associated public water supply and irrigation demands

Table 2. Key Assumptions used in the Regional Model (SFWMM)

Item	Scenario/Alternative*					
	1	2	3a	4a	3b	4b
General system-wide features (from LECRWSP)	1990 base	1990 base	1990 base	1990 base	2010 base	2010 base
Landcover outside Lake Belt	1988	1988	1988	1988	2010	2010
Landcover within Lake Belt						
a acreage of lakes	no lakes	5,120 acres	10,240 acres	25,600 acres	10,240 acres	25,600 acres
b extent of melaleuca	20,480 acres	20,480 acres	20,480 acres	7,680 acres	20,480 acres	7,680 acres

* Hydrologic Condition 1965-1990 period, daily output

It is important to understand that the model cannot exactly mimic the fine-scale landuse "polygons" of various shapes and details depicted in the landuse map Typically, the model grid (2 mile x 2 mile) is overlaid on a detailed landuse map and a landuse category is assigned to the each cell based on the predominant landuse category The acreage corresponding to model cells assigned for various scenarios are shown in Table 2

Evapotranspiration of Melaleuca versus Open Water

The 1994 landcover map within the Lake Belt area shows that the study area consists of large strands of Melaleuca Unfortunately, there is limited information available regarding the evapotranspiration (ET) rates of Melaleuca For this study, the recent report on ET rates of Melaleuca (Chin, 1996) was used to select appropriate parameters for modeling melaleuca ET in the regional model The method includes two factors for determining melaleuca losses in the lake belt region First, Chin (1996) calculated the actual evapotranspiration rates for melaleuca utilizing the Penman-Monteith method In addition to the Penman-Monteith ET rates calculated for melaleuca, Chin (1996) suggests that a second component be added which accounts for evaporative losses due to interception of rainfall within the melaleuca canopy It is assumed that these interception losses are removed from the system during heavy rainfall events and not available as recharge to the aquifer or for utilization by the vegetation In order to determine the interception losses, Chin (1996) utilized Woodall's (1984) empirical equation for estimating interception losses The result is that Chin (1996) determined that the maximum ET rate for melaleuca is approximately 51 in/year plus an interception loss of approximately 12 in/year resulting in a total loss of 63 in/year

At first glance, it would seem that the ET rates for melaleuca and open water are essentially the same and, therefore, the change from melaleuca forest to open water systems should have minimal impact in the overall water balance for the region However, this is rarely the case The reason is the time variant nature of ET and rainfall in south Florida and how that impacts these two very different systems

The lake systems are large open water bodies directly connected to the Biscayne aquifer Because of this, rainfall that falls on the lake system directly recharges the Biscayne aquifer However, rain does not occur constantly and there are extended periods of time when the lakes are evaporating with no rainfall to offset the losses Because the lakes are directly connected to the Biscayne aquifer, the lakes will evaporate at 63 in/year from the Biscayne aquifer regardless of the amount of rainfall that falls

On the other hand, the total losses from the melaleuca forests are a combination of interception losses during rainfall events and ET from the melaleuca plants (Chin, 1996) In this case, when it does not rain for an extended period of time, the maximum ET rate for melaleuca is about 51 in/year which, is less than the 63 in/year for the lake systems The actual ET rate from the Biscayne aquifer for melaleuca would tend to be less than 51 in/year during the dry periods due to reduced water availability in the unsaturated zone for use by the plant The depth to the water table also can affect the ET rate Melaleuca ET rates are assumed to start declining when the water table drops 18 inches or more below ground surface

Because of the uncertainty associated with the ET rates of Melaleuca versus Open Water, a sensitivity analysis will be conducted to investigate the implications of the assumptions made in this analysis

Regional Modeling Results

From the results of the regional modeling runs, the specific measures of success were quantified and summarized in Table 3 It should be noted that only a limited number of measures that are relevant for evaluating the performance of the initial set of scenarios are reported here Again, it is noted that Scenarios 1,2,3a, and 4a correspond to the "1990 base condition" and are comparable Scenarios 3b and 4b shown in the last two columns correspond to the "2010 base condition " The measures of success relevant to urban water supply issues are separated from those important for environmental enhancement and protection

Without conducting rigorous statistical tests, the following preliminary observations were derived from the review of Table 3 and the other results from the regional modeling

Water Supply

1 There appears to be no significant change in water restrictions in Service Area 3 (primarily Dade County) This seems to be the case for both "1990 base condition," (Scenarios 1 through 4a) as well as "2010 base condition " (Scenarios 3b and 4b) The increase from the 1990 base to 2010 base is due to the associated projected increase in demand

2 From Scenario 1 to 4a, there appears to be a general decrease in regional system water deliveries to Service Area 3 The decrease occurred only for the deliveries made from Water Conservation Areas In particular, the average annual water supply delivered via S-337 decreases slightly The most significant decrease is in the water supply deliveries made to the Northwest Well Field Protection Canal (Structure NWWFLW in Table 3)

3 There appears to be no marked change in the number of times the recommended minimum level criteria for salt water intrusion is not met

Environmental

4 There is no significant change in the average annual flows across the Tamiami Trail flow section for both wet and dry seasons

5 Frequency of ponding in eastern WCA-3B decreases markedly when the Scenario 3a (permitted lakes) is compared with Scenario 4a (Miners Proposed Initial Plan) This appears to be related to an increase seepage loss to the east from WCA-3B Another indication of the negative effect caused by the increased seepage is the general decrease in hydroperiod in eastern WCA-3B as shown by the hydroperiod-match statistics shown in Table 3

6 There appears to be no major change in the average flows to Biscayne Bay

7 There is an increasing trend in the seepage lost (Figure 3) to the east from WCA-3B as Scenarios are compared from No Lakes condition to the Rock Miners Initial Plan Average annual seepage loss in the form of regional groundwater flow to the east increases significantly for the Dry year of 1989, when Scenario 4 (Proposed Rock Miners Initial plan) is compared with Scenario 3 (Permitted Condition) This is the likely cause of the hydroperiod decrease in eastern portion of WCA-3B

8 Comparison of Scenarios 1 through 4a shows that the ponding depth and frequency in Pennsuco wetlands (Figure 2) is affected significantly, particularly when 3a is compared with 4a The increased groundwater flow to the east resulting from the lakes appear to be the primary reason for the declining water levels and hydroperiod in Pensucco wetlands

Summary

The most significant effect of the increasing the extent the extent of lakes as modeled modeled in Scenarios 1 through 4a appears to be in the form of declining hydroperiods in the Pennsuco wetlands and in eastern portions of WCA-3B The modeling results show that the Miners Proposed Initial Plan would increase the seepage to LEC near WCA-3B when compared with the Scenarios of Permitted Lakes or lesser The regional system deliveries to Service Area 3 appear to decrease slightly when plan are compared from 1 through 4a The water delivery to North West Well Field appears to decrease significantly in the case of Miners Proposed Initial Plan with extensive lakes in the Lake Belt area No effort has been made to determine the ecological implications of hydrologic changes demonstrated by the modeling results

Table 3. Summary of regional modeling result for initial alternatives

Measure of Success	Scenarios/Alternatives					
	1	2	3a	4a	3b	4b
WATER SUPPLY						
Number of months of water restrictions in SA3 (for the entire 26-year period)	44	44	45	45	69	67
a Phase 1	0	0	0	0	0	0
b Phase 2	0	0	0	0	0	0
c Phase 3						
Average Annual Regional Water Supply to SA3 (1000 acre feet)						
a From LOK	43	42	42	41	45	45
b From WCAs	78	70	68	64	44	41
c S337	120	111	109	105	84	83
d S335	115	114	106	92	106	83
e S31	0 5	0 8	0 9	0 2	5	3
f NWWFLD	26	16	12	3 4	7	2
Regional Water Supply to SA3 during Drought years (1000 acre feet)						
a From LOK	116	116	115	114	126	124
b From WCAs	99	94	94	89	80	73
Number of times stage < Saltwater intrusion criteria and duration > 1 week						
a C-9	11	7	5	8	13	10
b Miami Canal	2	4	4	2	6	3
c C-4	1	2	2	2	1	1
d C-2	2	2	2	2	3	3

Table 3. Summary of regional modeling result for initial alternatives (Cont.)

Measure of Success	Scenarios/Alternatives					
	1	2	3a	4a	3b	4b
ENVIRONMENTAL						
Average Annual Flows across Tamiami Trail flow section (1000 acre feet) a Wet Season (NSM V 4 4=554) b Dry Season (NSM V 4 4=544)	466 285	470 287	469 287	467 285	446 293	435 287
Average depth of ponding in eastern WCA-3B (feet) Duration (% of time) of ponding	0 96 67%	0 96 65%	0 96 61%	0 94 46%	1.16 64%	1.16 55%
Hydroperiod Match in WCA3B (69,000 acres) compared to NSM (1000 acres)[1] a 270-365 shorter b 180-270 shorter c 90-180 shorter d 30-90 shorter e 30 longer/shorter f 30-90 longer g 90-180 longer h 180-365 longer	0 5 1 10 2 25 6 25 6 2 6 0 0	0 5 1 10 2 25 6 25 6 2 6 0 0	0 5 1 12 8 23 0 25 6 2 6 0 0	0 12 8 12 8 20 5 23 0 0 0 0	0 2.6 15.4 20.5 30.7 0 0 0	0 5.1 15.4 23.0 25.6 0 0 0
Average Annual Flows to Biscayne Bay (1000 acre feet) a Northern (dry/wet) b Central (dry/wet) c Southern (dry/wet)	189/41 472/18 6 46/153	187/41 0 70/183 46/152	190/40 3 69/183 44/150	202/40 9 68/176 41/145	179/39 3 66/174 42/127	191/400 69/171 41/126
Average Annual Total seepage from WCA-3B to LEC (1000 ac ft)	189	194	198	229	231	253
Total seepage (1000 ac ft) from WCA-3B to LEC during 1969 (WET)	292	295	299	312	356	361

Table 3. Summary of regional modeling result for initial alternatives (Cont.)

Measure of Success	Scenarios/Alternatives					
	1	2	3a	4a	3b	4b
Total seepage (1000 ac ft) from WCA-3B to LEC during 1989 (DRY)	81	85	91	128	86	127
Average depth of ponding depth in Pennsuco wetlands (feet)	1 11	1 09	1 01	0 87	1.13	1 03
Duration (% of time) of ponding	76%	73%	71%	52%	77%	62%

1 A perfect match with NSM hydroperiod would show all 69,000 acres in WCA-3B in the 30 days longer/shorter category

SENSITIVITY ANALYSIS OF MELALEUCA ET USING SOUTH FLORIDA WATER MANAGEMENT MODEL (SFWMM)

Due to some uncertainty associated with the extinction depth of Melaleuca trees, and hence their ET rate in comparison with ET from open water as well as the possible implications the large acreage of both Melaleuca and Open water Lakes may have on the model results and conclusions, a Melaleuca ET sensitivity analysis was conducted

In the SFWMM, Melaleuca ET starts declining when the water table drops to 18 inches (shallow root zone assumed for Melaleuca) or more below ground When the water table drops to 3 feet (extinction depth assumed for Melaleuca) or more below ground, model simulated Melaleuca ET drops to zero Thus, among other things, the actual Melaleuca ET simulated by the model depends on these parameters An upper bound of Melaleuca ET can be obtained by increasing the extinction depth to a large value (so that Melaleuca ET is close to its maximum potential rate of 51 inch/yr) and see if the important performance measures are affected significantly

The four scenario runs (#1, #2, #3a and #4a as discussed in the report presented to the Lake Belt Committee on July 19, 1996) were re-run after increasing the Melaleuca shallow root zone depth and extinction depth to large values (from 18 inches and 3 feet to 100 and 200 feet, respectively) In addition, the irrigated acreage was set to zero for those Melaleuca cells in the Lake Belt region of the model that had any type of irrigation This was done because the SFWMM performs unsaturated zone accounting for all irrigated cells in the model and thereby the saturated ET coming out of the non-irrigated portion of the cell is limited by the composite crop PET for the cell (for further discussion, please see memorandum "Revised methodology for integrating pre-processed irrigation demands and Unsaturated zone evapotranspiration into the SFWMM" dated November 23, 1993 from

Cal Neidrauer to Ken Ammon) Setting the irrigation to zero in the Sensitivity runs further pushes Melaleuca ET towards its upper bound value

Table 4, shows rainfall and ET for typical Melaleuca (with no irrigation) and open water cells in the study area Row1 is the annual average rainfall amount input to the cell while row2 and row4, respectively, are the rainfall intercepted and returned to the atmosphere by the Melaleuca canopy Row3 represents the balance rainfall that falls on the ground while row5 is the total ET from the aquifer

As can be seen from the table, for the Lakebelt Present Condition Base run, the ET from the aquifer is 41 in/yr and the net RF-ET = +0 9 in/yr In contrast, for the Lakebelt Present Condition sensitivity run, ET from the aquifer increases as expected to about 50 in/yr which is closer to the potential ET of Melaleuca used in the model (51 in/yr) In addition, the net RF-ET also changes to a deficit value of -8 5 in/yr which is closer to RF-ET for open water (-6 2 in/yr from column (4) in the table) Thus, the combined effect of increasing the extinction depth and turning the irrigated acreages to zero was to bring up the Melaleuca ET close to that of open water (as determined by Chin(1996))

Table 4: Rainfall and ET (65-90 average annual values in inches/yr), for a typical Melaleuca and Open Water cell (cell area 2560 acres).

		Melaleuca Cell (sfwmm Row 25 Col 28)		Open Water Cell (sfwmm Row 26 Col 29)	
		LKB2 Present Condition Base run (1)	LKB2 sensitivity run (2)	LKB2 Present Condition Base run (3)	LKB2 sensitivity run (4)
1	Rainfall	53 8	53 8	56 2	56 2
2	Rainfall interception	12 1	12 1	n/a	n/a
3	Rainfall on ground	41 7	41 7	56 2	56 2
4	Interception losses	12 1	12 1	n/a	n/a
5	Total ET	40 8	50 2	62 8	62 8
6	RF(row3) - ET(row5)	+0 9	-8 5	-6 6	-6 6

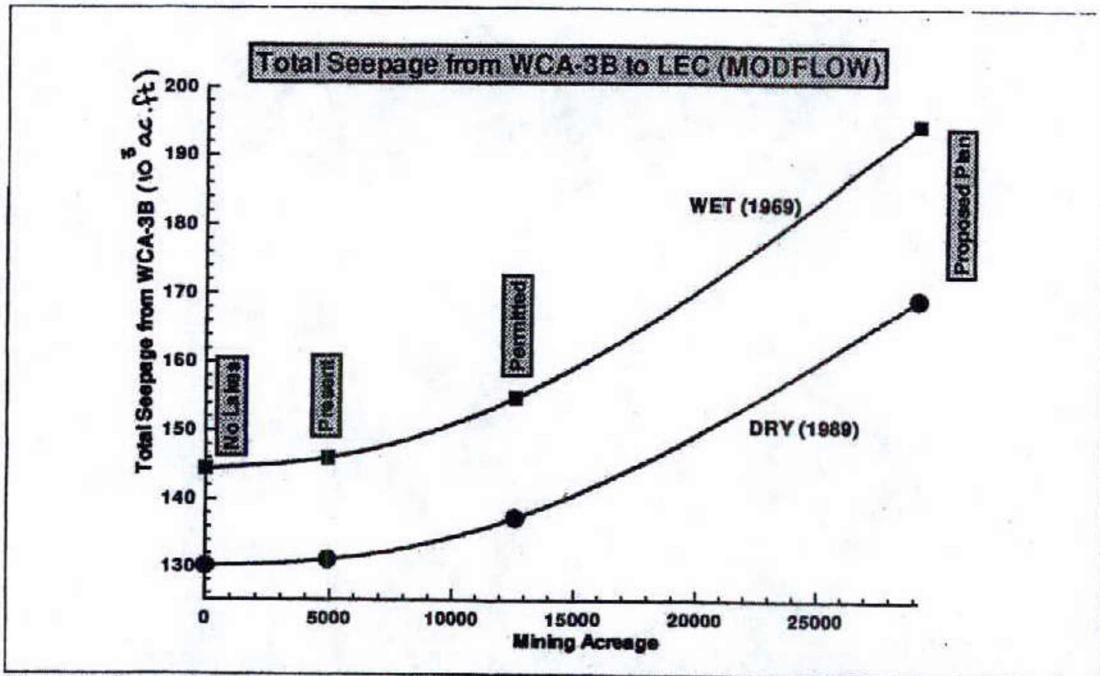

Figure 4 Seepage from WCA-3B simulated by the MODFLOW model

The primary interest from these sensitivity runs is to see what effect this increased ET over the region has on the model results and conclusions drawn from the previous set of base runs Fig 4 displays the comparison of seepage lost from WCA-3B to the east across L-30 levee for the two sets of runs It can be seen that increasing ET from Melaleuca has an insignificant effect on the increasing trend of seepage lost from WCA-3B to the east as more mining is done The slightly higher seepage in 1989 (dry condition) is to compensate for the higher ET loss occurring over the region A decreasing difference between the 1989 total seepage can be noticed as mining acreage increases This is due to the fact that the more lakes scenario has lesser Melaleuca acreage and so the base and sensitivity runs are similar

The ponding depths and the duration of flooding in Pensucco wetlands (fig 2) also show similar results as in the previous set of base runs The area is significantly affected in Scenario 4a as compared with Scenario 1 (as was also seen shown from the earlier set of base runs) A few other key regional performance measures were also examined (flows to Biscayne Bay, hydroperiods and Water levels in WCA-3B, etc) to see the effect of increased Melaleuca ET The results that were noted from the earlier set of runs (that used 3 feet extinction depth for Melaleuca) are insensitive to changes in the extinction depth

In summary, the uncertainty associated with ET rates for Melaleuca does not have any significant impacts on model results and conclusion

Literature Cited

Chin, D A, 1996 Research Plan for the Study of Melaleuca Evapotranspiration Technical Report No CEN-96-1 University of Miami, FL, 133 p

Woodall, S L , 1984 Rainfall interception losses from melaleuca forest in Florida Research Note SE-323, U S Department of Agriculture, Southeastern Forest Experiment Station, Forest Resources Laboratory, Lehigh Acres, FL

ATTACHMENT 1
Expanded Measures of Success

Incorporates changes made at Technical Workshop Sessions on June 7 & 14, 1996
Refined measures of success are shown in *italics*
Revisions to measures of success are <u>underlined</u>

Objective 1: Enhance Water Supply for Dade County and the Everglades

Measures of Success

- Extent to which water supply for Dade County is enhanced <u>under the following pumping demands.</u>
  *155 MGD**
  *198 MGD***
  *245 MGD***
  *380 MGD***
  - *Water Levels for Salt Water Intrusion*
  - *Number of Water Shortage Cutbacks*
  - *Regional Surface Water Deliveries*
  - *Spatial Maps of Drawdowns*
  - *One foot drawdown at Dade Broward Levee in a drought with a ten year return period*
  - *Maintenance of Snapper Creek Canal as hydrologic barrier*

* *pumpage from both Northwest and Miami Springs wellfields, max day*
** *pumpage from Northwest wellfield only, max day*

- Extent to which hydroperiod and flows are enhanced for the Everglades including Florida Bay
  - *Flow across Tamiami Trail (compared to NSM)*
  - *Hydroperiod Maps (compared to NSM)*
  - *Hydroperiod Maps (compared to MF&L)*

- Extent to which wet and dry season flows <u>enhance</u> Biscayne Bay
  - *Wet and Dry season surface water flows into Northern, Central and Southern Biscayne Bay*
  - *Wet and dry period flow hydrographs flows into Northern, Central & Southern Biscayne Bay*

- Extent to which the Lake Plan meshes with state and regional plans being developed -

- Amount of water available during drought conditions for Dade County and the Everglades system including Biscayne Bay, Florida Bay, and South Florida estuaries
  - *No detrimental changes in Primary and Secondary Standards*

- *No incidence of contamination with Criptosporidium or Giardia*
- *No changes in water classification of wellfield*
- *No degradation of surface water quality within the lake belt (except for water quality treatment areas) resulting from*
  - *a Recreation*
  - *b Mining*
  - *c Backpumping*

- Effects of plan on potable water quality and Northwest Wellfield groundwater designation

- Quality of the water being made available for Dade County and the Everglades system
  - *Water Supplied to the Everglades must meet applicable Everglades water quality standards*

Objective 2: Maximize Efficient Rockmining

Measures of Success

- Total volume of rock available for mining through 2050

- Proximity of lands available for rockmining to processing and transportation facilities

- *Quantity of minable lands within a reasonable distance of appropriate (crusher locations, rock processing facilities)*

- *Efficient mining pattern or layout*

- Extent to which future governmental permitting requirements are made more certain *Within the confines of the Plan, the ability of miners to quantify reserves with certainty*

- *The extent to which the dredge and fill permitting process is made more cert*ain

Policies

- *Design and phasing such that blasting impacts are minimized*

- *Design and phasing such that impacts of quarry operations such as dust and noise are minimized*

- *Design and phasing such that attractive nuisance aspects of quarry operations are minimized*

- *Flexibility of quarry operators to operate within the Lake Belt Plan.*

Objective 3: Promote the Social and Economic Welfare of the Community

Measures of Success

- Extent of recreational opportunities
  - *Provides for Managed public access to recreational resources*
  - *Provides supply for existing and proposed recreational demand*
  - *Provides for diversity of compatible recreational opportunity*
  - *Provides for cost effective management of recreational areas.*
- Diversity of opportunities *(narrative)*
- Economic vitality of rock mining industry *(narrative)*
- Economic vitality of other industries *(narrative)*
- Compatibility of land uses *(narrative)*
- Addresses rights of all private and public land owners, large and small *(narrative)*
- Economic value of clean, quality environment *(narrative)*
- Compatibility with transportation plans *(narrative)*
- Extent to which the Lake Plan provides for a sustainable South Florida *(narrative)*
- Costs of infrastructure construction, operation, and maintenance *(narrative)*
- Protection of public health *(narrative)*
- Avoidance of risk to potable water quality and preservation of groundwater designation of the Northwest Wellfield *(narrative)*
- Provision for the acquisition or compatible lawful use of parcels not intended for rock mining *(narrative)*

Objective 4: Protect the Environment

Measures of Success

- Extent to which the Everglades including WCAs and Florida Bay are preserved, enhanced, and restored
  - *Seepage lost from everglades*
  - *Flow across Tamiami Trail (compared to NSM)*
  - *Hydroperiod Maps (compared to NSM)*
  - *Hydroperiod Maps (compared to MF&L)*
  - *Hydroperiod and ponding maps*

- Extent to which wet and dry season flows <u>enhance</u> Biscayne Bay
  - *Wet and Dry season surface water flows into Northern, Central and Southern Biscayne Bay.*
  - *Wet and dry period flow hydrographs flows into Northern, Central & Southern Biscayne Bay.*

- Amount, quality, and the extent to which the habitat within Lake Belt is created, preserved, enhanced, and restored including biological productivity of lakes and littoral areas

- The extent to which the habitat created, preserved, enhanced, or restored <u>offsets the biological functions of the existing habitat lost</u>.

- Amount of exotic vegetation removed and controlled

- Extent to which habitat functions resulting from the Plan are protected from impacts from future development.

- Extent to which water quality is enhanced

Revised: December 12, 1996

HYDROLOGY

INITIAL LAKEBELT MODELING RESULTS

PART II. SUBREGIONAL MODELLING STUDY

Executive Summary

A ground water flow model was developed for the Lake Belt region comprising of Northern Dade and Southern Broward Counties. The model was used for analyzing the hydrologic impacts of the alternate mining configurations identified by the Lake Belt committee. The various model simulations were performed for current configurations of surface water features under both wet and dry hydrologic conditions. Modeling results were evaluated by considering the following Performance Measures:

- Seepage from WCA-3B across the L-30 levee
- Net areal recharge within the Lake Belt region
- Range of increase/decrease in water table elevation within the Pennsuco wetlands

The analysis examined a wide range of scenarios involving different foot prints of mined lakes ranging from the hypothetical "no-lakes" condition to a maximum extent of mined lakes as envisioned in the South Florida Limestone Mining Coalition's Initial Plan. The results revealed an increasing trend in the seepage lost to the east from WCA-3B as the mining area increased, and this relative increase in seepage became noticeably larger when the regional extent of mining included large portions of the FPL strip and lands in the Pennsuco wetlands. The simulated net areal recharge (rainfall minus evapotranspiration) rates on the other hand, exhibited a decreasing trend with increasing mining area. Furthermore, the results also showed that mining configurations that encroached into the Pennsuco wetlands resulted in salient water table drawdowns (from current conditions) within these wetlands.

Introduction

The Florida legislation (Ch. 373.4149 (4)) created the Northwest Dade County Freshwater Lake Plan whose mission is to create a plan for the efficient recovery of limestone from the Lake Belt region while promoting the welfare of the community and protecting the environment. In order to achieve this mission, the Lake Belt committee had adopted a set of objectives and performance measures. The ground water modeling study presented here was undertaken to address the following important question:

- What are the regional and local hydrologic impacts/benefits due to increasing extent of lakes created by rock mining?

While this question was also addressed in the regional modelling study, the resolution of the regional model was not adequate to examine in detail the entire set of alternative mining configurations selected by the Lake Belt committee. In addition, it was felt that a subregional modelling analysis would be useful for confirming and/or refining the results of the regional modelling analysis. Consequently, the subregional modelling study discussed herein attempted to address the primary objective indicated above while supplementing and refining the results of the regional modelling analysis.

General Model Features

The Lake Belt MODFLOW model encompasses the portions of southern Broward County and Northern Dade County as shown in figure 1. The northern boundary of the active model domain is located along the C-11 canal in Broward County while the southern boundary extends from the ENP, through the C-1 and C-100 canal basins and to the coast (figure 1). The eastern boundary is located along the coast and the western boundary includes part of the L-67C levee. The boundaries were located far enough from the Lake Belt mining area so that the effects of boundary conditions on model output within this area would be minimal. In addition, extending the active model domain to the limits shown in figure 1 will enable the model to address the impacts of mining alternatives on certain locations of interest outside of the Lake Belt.

Figure 1 also illustrates the major hydrographic features that were incorporated into the model. These include canals, lakes, wetlands, Biscayne Bay and the Atlantic Ocean. The canals include both primary and secondary canals while the lakes shown in figure 1 include limestone mining lakes as well as lakes constructed for private developments. The major wetlands of interest are WCA-3B and the Pennsuco wetlands located between the L-30 Levee and the Dade-Broward Levee.

All major municipal wellfields are also included in the model. Among the largest are the Northwest, Preston, Miami Springs, Hialeah, Southwest, Snapper Creek and Alexander Orr wellfields.

The model encompasses nearly all of the Surficial Aquifer System (SAS) within the study area. The SAS includes the Miami Oolite, the Fort Thompson Formation and the Tamiami Formation (see Fish and Stewart, 1991). The Fort Thompson Formation contains the Biscayne Aquifer, the primary water bearing unit within the model domain and one of the most transmissive aquifers in the world.

In order to represent all of these features in the model with acceptable accuracy while minimizing the time required for processing model input and output, the time required for model execution and computer storage requirements, a constant grid cell size of 1000 feet x 1000 feet was selected. This model grid is depicted in figure 2. Furthermore, the SAS was discretized into seven model layers. Layer one extends from land surface down to an elevation of -10 feet NGVD, layers 2 through 4 are each 20 feet thick and layers 5, 6 and 7 are each 30 feet thick. This comprises the SAS down to an elevation of -160 feet NGVD.

Model Details

Boundary Conditions

The outer model boundary shown in figure 1 was modelled as a head-dependant flux boundary using the General Head Boundary package. Along the northern boundary, the specified heads correspond to stages in the C-11 canal. Similarly, heads along the southern boundary correspond to measured water levels in the ENP, stages in the C-1W, C-1N, C-100 and C-100A canals, and tidal elevations. Eastern boundary heads were set equal to measured tidal elevations while heads specified at the western boundary reflect stages in WCA-3B measured near this boundary.

Hydrologic Stresses

The hydrologic stresses applied to the model include ET, recharge from rainfall, ponded surface water, canal-aquifer interactions and water supply pumpage. ET was accounted for in the model through the ET package. Required input to this package includes an ET surface array depicting the elevations at which evapotranspiration from the water table occurs at a maximum rate, an array containing maximum evapotranspiration rates and an extinction depth array that represents the water table depth below the ET surface where evapotranspiration rates from the water table become negligible. The ET surface and extinction depth arrays were based on land surface elevations as well as representative shallow and deep root zone depths, respectively, for all vegetative land covers found within the model domain. The maximum evapotranspiration rates were estimated by conducting a daily water balance on the root zone for each unique combination of land cover and soil type, as outlined in Restrepo and Giddings (1994). This water balance analysis also yielded daily amounts of infiltrated rainfall reaching the water table. These results were used to construct the arrays depicting rainfall recharge to the water table and were input to the model using the Recharge package.

Canal-aquifer interactions were modeled using the River and Drain packages. These packages are similar except that the Drain package only allows ground water to flow from the aquifer to the channel whereas the river package will account for ground water flowing in either direction. In classifying the various canal reaches within the model domain as either "Rivers" or "Drains", consideration was given to the amount of base flow accumulating in upstream reaches, releases into the canal reaches from upstream structures, potential impacts from wellfields and confluences with downstream channels. Required input to each of these packages includes model cell location, canal stage and a conductance term depicting the degree of hydraulic conductance between the channel and the aquifer. In addition, the River package requires as input the bottom elevation of each canal reach.

Pumpage from water supply wellfields reflected total monthly withdrawal rates reported for 1989. These pumpages were obtained from the monthly operating reports submitted to the District's Regulation Department. Within each wellfield, the total monthly withdrawals were allocated to each of the wells on the basis of their pumping capacities and stand-by statuses.

The effects of ponded surface water in WCA-3B and the ENP were included in the model by treating these ground water - surface water interactions as head-dependant flux boundaries. The General Head Boundary Package was used to incorporate these boundaries into the model and the surface water stages required as input to this package were computed by the South Florida Water Management Model (SFWMM) for the "current conditions" scenario. Consequently, these stages depict water levels under wet or dry hydrologic conditions for current land uses and structure operation rules. In particular, under dry hydrologic conditions, the SFWMM simulations indicated that average water levels within the ENP were below land surface, suggesting that no ponded surface water was present. Nonetheless, these stages were still input to this model to help ensure that computed water levels in the ENP were in good agreement with the SFWMM simulation results.

<u>Lakes</u>

Lakes were represented in the model as zones within the aquifer system with very high hydraulic conductivity (100,000 ft/day) and very high specific yield (1.00). Storage coefficients for these zones were based solely on the compressibility of water. Furthermore, it was assumed that each lake bottom is covered with a fine sediment bed that is 3 feet thick and has a hydraulic conductivity of 0.1 ft/day.

Lake locations and planforms were obtained from a January 1994 land use GIS coverage and verified with a January, 1994 SPOT image. In order to represent lake planforms in the model as accurately as possible, values of hydraulic conductivity, vertical conductance, storage and specific yield for model cells containing both open water and aquifer material were based on an aerially weighted average of the appropriate values for the aquifer material and those depicting open water. Estimates of lake depths were obtained from the South Florida Limestone Mining Coalition and were used to determine the number of model layers penetrated by each lake.

<u>Model Calibration</u>

Calibration of the Lake Belt MODFLOW model consisted of primarily two tasks: (1) the history matching of groundwater levels at USGS observation wells and DERM monitoring wells, and (2) the history matching of base flow volumes for selected canal reaches located between flow monitoring stations. In the history matching of ground water levels, daily water levels computed by the model were compared to measured daily water levels at well locations. The model was considered to be calibrated at a given well location on a given day if the difference between the measured and computed water levels was less than 0.5 feet. In the history matching of base flow volumes, on the other hand, model - computed base flow volumes within selected canal reaches for selected 7-day periods were compared to measured volumes for the same 7-day periods. Adjustments to model parameters were made until reasonable agreement between measured and computed flow volumes was obtained.

The period of record for model calibration is July 4, 1994 through December 31, 1994. Calibration through the end of 1993 has been completed for the portion of the model domain located within and in the vicinity of the Lake Belt mining area. During this time period, however, data for base flow calibration were limited and calibration criteria were not met for every observation well and canal reach. Also, prior to initiating calibration, a test was performed to determine the number of days from the beginning of the calibration period that a simulation would have to progress before computed head values became insensitive to initial conditions. It was found that this length of time is approximately 100 days. Consequently, model output for the first 118 days of the calibration period was not used.

GIS Database

All spatial data needed to construct and run the model were managed and edited using a GIS system. The GIS software used for this purpose was ARC/INFO, the primary GIS software used by the District. The GIS database was designed to allow for organized management of all spatial data as well as convenient construction and modification of model data sets.

The contents of this GIS database includes point, line and polygon coverages, grids, AML (Arc Macro Language) programs and documentation. Examples of polygon coverages include land use and the model grid while all canals as well as the outer model boundary are represented as line coverages. Point coverages were used primarily to depict well locations. Grids, often referred to as raster coverages, were used to represent all matrix type input to the model and were usually derived from polygon or point coverages. In addition, documentation files were written for most of the grids and coverages, where the documentation includes data sources, procedures used to construct the grids and coverages, discussions on data quality issues and, where appropriate, edit logs. Finally, AML (Arc Macro Language) programs were used to convert grids and coverages to model input data sets as well as to convert model output to grids and coverages.

Alternative Mining Configurations

Eight scenarios/alternatives were identified by the Lake Belt Committee for the ground water modeling analysis. These are essentially "non-structural" scenarios that only increase the extent of rock mining in the Lake Belt region. They are identified as scenarios 1 through 8 in Table 1 along with their corresponding mining acreages. Also, it should be noted that the numbering of the scenarios is somewhat arbitrary and not necessarily in the same order as increasing mining acreage.

Scenario No.1, called the "NOLAKES" scenario, provided insight into the question, "What if there were no lakes?". Although it is not a realistic alternative for implementation, this alternative can provide an important basis for comparison.The land use coverage used for this alternative was the current (January, 1994) land use coverage with the exception that the mining lakes in the Lake Belt area were "filled" with an appropriate land use based on the surrounding land cover.

Scenario No. 2, called the "CURRENT CONDITIONS" scenario, is based on the current configuration of lakes and reflects the land use existing as of January, 1994 with the melaleuca areas within the Lake Belt area modified to reflect the work done by EAS Associates (1994). This scenario served as the base scenario for comparison purposes.

Scenario No. 3, termed "PERMITTED", is based on a Lake Plan which not only includes the existing lakes but also all lakes that are currently permitted to be mined in the future.

Scenario No. 4, termed "PRMIP" (Proposed Rock Miners Initial Plan), is based on a Lake Plan presented by the South Florida Limestone Mining Coalition in the 1995 Northwest Dade County Freshwater Lake Plan Implementation Committee Progress Report. It is derived from a plan for maximizing mining while adhering to a series of land use constraints pertaining to public wellfields, major canals, FPL transmission lines, railroads, the prison, a cemetery and other facilities in the Lake Belt area. In particular, the plan includes mining in the entire FPL strip and portions of Pennsuco wetlands and, as seen from Table 1, contains the largest mining area.

Scenarios 5-8 are variations of Scenario 4, with total mining acreage less than that of Scenario 4. Scenario No. 5, called "PRMIP-PENN" (Proposed Rock Miners Initial Plan minus Pennsuco), is the same as Scenario 4 except it excludes any mining in the Pennsuco wetlands. Scenario No. 6, called "PRMIP-PENN-FPL" (Proposed Rock Miners Initial Plan minus Pennsuco minus FPL), is the same as Scenario 4 except it excludes any mining both in the Pennsuco wetlands and the FPL strip. Scenario No. 7, called "PRMIP-PENN-FPLNOWN" (Proposed Rock Miners Initial Plan minus Pennsuco minus FPL no ownership), is the same as Scenario 6 except it allows the mining of lands owned by the Coalition within the FPL strip. Scenario No. 8, termed "PRMIP-1BUFF" (Proposed Rock Miners Initial Plan minus 1 mile buffer along L-30), is the same as Scenario 4 except it incorporates a mining buffer along L-30 canal that is one mile wide and extends from Miami Canal to Tamiami Trail.

Model Scenarios

<u>Steady State Scenarios</u>

Under "steady state" conditions, all of the hydrologic factors that affect the ground water levels and flows within the Lake Belt region are held constant at a certain level or rate corresponding to a wet or dry hydrologic condition. Here, hydrologic conditions for 1969 and 1989 were used to represent wet and dry hydrologic conditions, respectively. Steady state simulations represent equilibrium conditions within the study area under the selected wet or dry conditions and they are useful for understanding the hydrologic behavior of various alternative mining configurations.

For the wet and dry years mentioned above, the surface water stages required as input to the model were derived from transient SFWMM output and represent annual average values for the respective years. Recharge to the water table and maximum ET rates also reflect average annual conditions for each of these years. Pumpage rates were varied over four different scenarios for the Northwest and Preston - Miami Springs - Hialeah wellfields as shown in table 2. Pumpage rates from all other wellfields were set equal to their 1989 average annual values.

The following performance measures were used to evaluate the results of the steady state scenario simulations:

1. Seepage from WCA-3B across the L-30 levee between structures S-32A and S-335;
2. Net areal recharge (rainfall recharge minus ET) within the Lake Belt region;
3. Range of increase or decrease in water table elevation within the Pennsuco wetlands relative to current conditions.

Transient Scenarios

Transient simulations are, by nature, complex and time consuming. Therefore, in order to save time and effort, only the scenarios involving the 1989 average annual pumpage (155 mgd) from the NW Wellfield were simulated under transient conditions. Both the 1969 and 1989 years were simulated using daily stress periods to depict time-varying rainfall, evapotranspiration, surface water stages and pumpage. The same data sources used for the steady state scenarios were used to construct the transient input data sets. Also, in order to minimize the effects of initial conditions (i.e. the conditions at the beginning of 1969 and 1989), one year preceding each of these years (i.e. 1968 and 1988) was included in each of the simulations as a "warm up" period. Finally, it should be emphasized that the primary objective of these transient simulations was to determine the drawdown at selected locations in the Pennsuco wetlands under the various configurations of quarries. These results can be used to supplement the results of the steady state simulations.

Since transient simulations require specific yield as input, the specific yield for the portion of the top model layer located within the Pennsuco wetlands was increased from a value of 0.2 to 0.9 during the simulations depicting the wet 1969 conditions when the wetlands were inundated for much of the year. This was done to account for the fact that water level fluctuations were occurring above ground. For the dry 1989 hydrologic conditions, on the other hand, the specific yield for layer 1 remained equal to 0.2 in the Pennsuco wetlands area since the water table was located below the ground surface for the entire simulation.

Steady State Scenario Results

The steady state results for the various pumpage scenarios are summarized in

Table 3 and are depicted graphically in figures 10 - 18. Figures 10 - 13 illustrate the effects of increasing mining acreage on seepage from WCA-3B while figures 14 - 15 depicts the corresponding phenomenon for the ENP. Figures 16 - 19 reveal the general trends of decreasing net aerial recharge with increasing mining acreage while figures 20 - 22 show the spatial distribution of steady state drawdown within the Pennsuco wetlands for several selected scenarios. *It should be emphasized that it is the general trends and changes relevant to current conditions (alternative 2) shown in figures 10 - 19 as opposed to specific values of seepage or net aerial recharge that are of primary importance in drawing the types of conclusions relevant to the objectives of this study.*

In regards to these results, however, it should be pointed out that the 1994 land cover map within the Lake Belt shows that the study area contains large strands of melaleuca. Unfortunately, there is limited information available regarding evapotranspiration (ET) rates of Melaleuca. For this study, information contained in Chin (1996), a recent report on Melaleuca ET rates, was used to select appropriate parameters for modeling melaleuca ET in both the regional model and the MODFLOW model. This report, the most comprehensive study to date of melaleuca ET rates in south Florida, presents melaleuca ET rates estimated with the Penman-Monteith method along with a simple empirical model for quantifying interception losses from dense forests such as Melaleuca. Chin (1996) notes that such interception losses can be significant. Also, in this analysis it was assumed that the ET extinction depth is not infinite as suggested by Chin (1996). The infinite ET extinction depth was considered to be unrealistic. Instead, a maximum root zone depth of 36 inches was assumed while the shallow root zone depth for melaleuca was taken to be 18 inches. Consequently, model-computed ET rates will diminish as the water table declines 18 inches or more below the ground level and will be equal to zero when the water table reaches a depth of 36 or more inches below the ground surface.

Because of the uncertainties associated with the model-calculated ET rates for Melaleuca, a sensitivity analysis was conducted to investigate the sensitivity of the trends revealed in figures 10 - 19 to the choice of extinction depth for melaleuca ET. In this sensitivity analysis, the ET surface elevations for model cells containing melaleuca as the primary vegetative cover were decreased from 18 inches to 60 inches below land surface in order to ensure that the model-calculated ET rates would be equal to the maximum rates. No other changes to model input were made. Also, the sensitivity analysis was only conducted for the scenarios involving 1989 average annual pumpage rates. The results of these model simulations are shown in figures 23 - 26. It can be seen that the general trends in seepage and net aerial recharge appear to be insensitive to assumptions regarding the extinction depth for melaleuca ET, assuming that 36 inches below land surface is a realistic minimum value.

Transient Scenario Results

As indicated previously, the transient simulations were used only to address one performance measure - the changes in groundwater levels at selected locations in the Pennsuco wetlands for the various rock mining configurations. Figure 27 identifies the model cells within the Pennsuco wetlands where stage hydrographs were analyzed from the transient runs. The hydrographs are shown in Figures 28-31 for 1969 (wet year) hydrologic conditions and in Figures 32-35 for 1989 (dry year) hydrologic conditions. For the wet year, the stage hydrographs show that mining configurations with a mining acreage larger than that of Scenario 6 lead to water levels significantly lower than those reflecting current conditions. It can also be seen that the drawdowns have a significant spatial variation. In particular, drawdowns are higher in the Northern Pennsuco wetlands near the Delivery Canal than drawdowns at locations within the South Central Pennsuco wetlands. In general, drawdowns appear to be larger at locations that are both close to a canal and far from the Northwest wellfield. The hydrographs for the dry year show similar behavior except the drawdowns are less than those computed for the wet year

The results of the transient runs are also presented in Table 4 as the number of days during the year where the ground water elevation was higher than the land surface elevation. Only the results for 1969 are provided here since the transient simulations for 1989 did not show any ground water elevations above land surface. From these results, it is apparent that the frequency of ponding is significantly less for those scenarios with mining acreages larger than that of Scenario 6. Also, the spatial distribution characteristics of this decrease in ponding frequency are similar to those of the water table drawdowns. For example, it is larger in the Northern Pennsuco wetlands near the Northwest wellfield Delivery canal than at locations in the South Central Pennsuco wetlands. The ponding frequency also decreases as one moves east towards the Dade Broward Levee.

Conclusions

After analyzing the results of both the steady-state and transient simulations, the modeling staff arrived at the conclusions discussed below.

<u>Seepage from the Everglades</u>

Although higher pumpages cause larger volumes of seepage, the trend in relative increase of seepage (as compared to the current condition) is similar for all pumpages investigated. For a given pumpage in Northwest Wellfield, there appears to be a "breakpoint" at or near Scenario 6. More specifically, the relative increase in seepage becomes noticeably larger when the regional extent of mining includes large portions of the FPL strip and lands in the Pennsuco wetlands.

Although the general trends in the seepage curves are similar, there can be variations due to both changes in hydrologic stresses (i.e. wet or dry) and pumpage from the Northwest Wellfield. In general, when the Lake Belt region is subjected to lower pumpage stresses, the relative effects of increased mining, when compared to the present condition under the same hydrologic and pumpage stresses, appear to be greater. The opposite appears to be true for larger pumpage stresses, which means that if pumpage from the NW Wellfield increases in the future, the "break point" in the seepage curve will move up to or near Scenario 7. This is especially true for drier conditions.

The proposed configuration of lakes south of Tamiami Trail appears to cause a significant increase in seepage across L-31N levee. This observation is consistent with what the modeling has shown north of the Trail in that the proximity of lakes to the north-south levees can have a significant influence on seepage. In general, both the proximity of lakes to the Everglades and the total area mined within the Lake Belt are factors that affect the relative increases in seepage (see figures 10 - 13).

It is important to note that the above findings are limited to the current configurations of the surface water features, such as canals and structures, and wellfields. Changes in these features can result in significant changes in seepage. The District modeling staff have not had the time to investigate the potential structural solutions that can lead to reduced seepage.

Water levels in Pennsuco Wetlands

Both the steady-state runs and the transient simulations show that, at certain locations within Pennsuco wetlands, mining configurations with a total mining acreage larger than that of Scenario 6 appear to cause noticeably larger drawdowns relative to current conditions. However, there appears to be definite spatial variability in the ranges of drawdown. Generally, the drawdown effect is larger adjacent to lakes and canals located away from the wellfield. It is also more pronounced during wetter periods such as 1969.

Water Supply

The net areal water table recharge (rainfall recharge minus evapotranspiration) appears to decrease with increasing mining acreage. This is a net loss of natural recharge from the Lake Belt region. However, the lakes appear to provide some water supply benefits. For example, earlier studies using the regional scale model (SFWMM) have shown that large extends of mining lakes can reduce the regional system deliveries to the Northwest wellfield protection canal. Also, at locations where mining occurs around the Northwest wellfield, the water table elevation generally increases due to the creation of mining lakes (see figures 20 - 22). Under certain conditions, increases in water table elevation can extend out into the Pennsuco wetlands (see table 3). In general, the benefits of lakes appear to be somewhat larger (across all scenarios) under conditions of higher stress (i.e larger pumpage and drier hydrologic conditions).

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Hydrologic Impacts of a Proposed Mining Plan with Structural Improvements in the Northwest Dade County Freshwater Lake Belt

by

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Executive Summary

In order to evaluate the effects of increased mining in the Lake Belt beyond the permitted mining configuration to a mining configuration suggested by the South Florida Limestone Mining Coalition, a total of six (6) ground water modeling scenarios were simulated. The first three scenarios depict currently permitted and proposed mining plans under wet annual (1969) hydrologic conditions while the last three scenarios simulated were the same as the first three except that they were based on dry (1989) historical hydrologic conditions. Under each hydrologic condition, the first scenario reflected the currently permitted mining configuration with no structural improvements while the second and third scenarios reflected the proposed mining plan with and without, respectively, structural improvements. All simulations were performed in a steady state mode.

The ground water modeling analysis of the proposed mining plan revealed that unless the structural improvements are implemented, decreases in average annual surface water levels within the Pennsuco wetlands may occur under wet annual hydrologic conditions. However, it is apparent that water levels within certain portions of the Pennsuco wetlands may still be impacted despite these improvements. Similar statements can be made regarding ground water levels in this area under wet or dry annual hydrologic conditions. Furthermore, the increased mining may result in higher ground water levels within the active mining area. These increases will be greater if the proposed structural improvements are implemented and may spread to parts of the surrounding urban areas. While this may pose as a water supply benefit during dry hydrologic conditions, it may result in a greater flooding potential as well as undesirable impacts to local infrastructure during wet conditions.

Maintaining the desired canal stages associated with the proposed structural improvements will require additional water from the regional system while these improvements may, in certain cases, result in significant changes to downstream canal flows. In addition, further analysis may reveal that slight modifications to the proposed structure configuration will be necessary.

Introduction

In order to evaluate the effects of increased mining in the Lake Belt beyond the permitted mining configuration to a mining configuration suggested by the South Florida Limestone Mining Coalition, a total of six (6) ground water modeling scenarios were simulated. The first three scenarios depict currently permitted and proposed mining plans under wet annual hydrologic conditions (based on 1969 historical rainfall). More specifically, one scenario involving the currently permitted mining configuration with no structural improvements was simulated along with two additional scenarios depicting the proposed mining configuration with and without, respectively, the structural improvements illustrated in figure 1. The last three scenarios simulated were the same as these first three except that they were based on dry historical (1989) hydrologic conditions. In all cases, simulations were performed in a steady state mode.

Performance Measures

Changes to ground water, wetland and, to a certain degree, canal flows were examined and compared across the scenarios under wet and dry annual hydrologic conditions in order to assess the impacts and benefits of the proposed mining plan relative to the currently permitted plan. To accomplish this, four performance measures that allowed for meaningful comparisons were used. These are:

- Changes in ground water levels within the Lake Belt and surrounding areas;
- Changes in ponded water depths within WCA-3B, the ENP and the Pennsuco Wetlands;
- Changes in canal base flows for selected canal reaches within the Lake Belt vicinity;
- Changes in ground water flows past selected key boundaries within the Lake Belt vicinity.

Scenario comparisons that are based on these performance measures are explained in detail below.

Analysis and Results

Changes in Ground Water Levels

Figures 2 and 3 show the changes in water table elevation between the scenarios involving increased mining activity without any structural improvements and the scenarios reflecting the permitted mining configuration. These figures show that the additional mining will reduce ground water levels within the Pennsuco wetlands and increase ground water levels in the area east of the Dade-Broward Levee. These figures also suggest that increased mining activity has little or no impact on ground water levels east of the C2 Extension canal.

Figures 4 and 5 show the changes in ground water levels between the proposed mining scenario with structural improvements and the permitted mining scenario while figures 6 and 7 show the changes in ground water levels for the proposed mining scenario resulting from the structural improvements alone. These plots show that while the proposed structures increase ground water levels in the Pennsuco wetlands, they also increase the ground water levels within a large area outside of the Pennsuco wetlands. Thus, only a portion of the water drawn from the regional water system to maintain these canals at the proposed levels will go toward increasing the water levels in the Pennsuco wetlands. In fact, figure 4 shows that even with these structural improvements there will still be some drawdown of ground water in the central Pennsuco wetlands. This suggests that the proposed structures are too distant from the central Pennsuco wetlands and that alternative improvements closer to this area should be investigated. Increased stages in the L-30 borrow canal may be one possibility.

Changes in Ponded Water Depths within Wetlands

The wetland module for MODFLOW was implemented in this study and allows surface flow within an extensive wetland to be simulated in conjunction with ground water flow. The major wetland areas pertinent to this effort include Everglades National Park (ENP), Water Conservation Area 3B (WCA-3B), the Pennsuco wetlands, and the northwest Bird Drive basin.

Figures 8 through 13 show the changes in wetland ponded water depth between the three scenarios for both wet (1969) hydrologic conditions and dry (1989) hydrologic conditions. It is interesting to note that figure 9 shows that nearly all of the wetlands were dry under dry steady state conditions for the permitted mines scenario. Also of interest is the fact that, under wet steady state conditions, the results showed no ponded surface water existing within certain areas of northeast WCA-3B as well as the eastern and southern Pennsuco wetlands. This appears to be in agreement with the results reported earlier for the Lake Belt Plan, where transient simulation results showed that ground water levels in the Pennsuco wetlands remained below land surface for extended periods of time, especially during the dry season. It should be emphasized that the 1969 average steady state conditions incorporated in this analysis include both the wet and dry seasons of 1969. Thus, the absence of ponded surface water on such an average annual basis is possible. In addition, figures 9 and 11 show that the increased mining, either with or without structural improvements, has little impact on ponded water levels under the dry 1989 hydrologic conditions since virtually no ponded water exists under these conditions for any of the scenarios.

Figure 8, on the other hand, illustrates the changes in ponding depths under wet annual hydrologic conditions between the scenario involving increased mining with no structural improvements and the base scenario reflecting the permitted mining configuration. This plot clearly shows a reduction in ponded water depths near the central Pennsuco wetlands. Moreover, figure 12 shows how the proposed structural improvements affect ponding depths under wet hydrologic conditions. These results show that the structural improvements may significantly increase ponding depths within the southern Pennsuco wetlands and the northwest Bird Drive basin. Lesser increases in ponding depth also occur in areas of WCA-3B and the Everglades National Park. Additionally, a comparison of figures 8 and 10 shows that the structural improvements effectively restore ponded water levels within parts of the Pennsuco wetlands if mining is increased from the permitted footprint to the proposed configuration.

Impacts to Canal Base Flows

Steady state water budgets were analyzed for selected canal reaches in the Lake Belt area (see figure 14). These include:

- the C-6 canal upstream of its junction with the C-2 Extension canal;
- the C-6 canal downstream of the C-2 Extension junction;
- the reach of the C-4 canal (along with its secondary tributaries) located west of the proposed structure at the Dade-Broward levee junction;

- the C-4 canal reach (along with its secondary tributaries) located between the structure proposed at the Dade-Broward levee junction and the proposed structure located at its crossing with the C-2 Extension and C-2 canals;

- the reaches of C-4 located downstream of its confluence with C-2 and C-2 Extension;

- the reach of the L-31N borrow canal located between its junction with C-4 and the proposed structure near the southern limit of the active mining area;

- the entire L-30 borrow canal.

The water budgets for the three scenarios are depicted in figure 15 for 1969 (wet) hydrologic conditions and in figure 16 for the 1989 (dry) hydrologic conditions.

The water budgets for the upstream reaches of the C-6 canal show that more ground water drains into the C-6 canal in the permitted mining plan than in the proposed mining plan. This is due to the fact that this reach of C-6 is maintained at a lower stage (for flood protection) compared to the surrounding ground water. Also, as more lakes are excavated, the effective increase in aquifer transmissivity allows for more flow of ground water into the C-6 canal. However, with the C-4/C-6 structures in place, there is a reversal of direction in the base flow for this reach of the canal as is indicated in figure 15 (by convention, flows into the aquifer from the canal are considered positive while flow into the canal from the aquifer is considered negative). In this case, the canal recharges the aquifer. This would mean that additional water needs to be supplied by the regional system to maintain the canal at the higher stage. The graphs show the same trends for this reach of the canal for both dry and wet average annual conditions. Also, it is apparent from figure 16 that the additional water demands on the regional system are greater under dry conditions compared to the wet conditions.

The water budgets for the downstream reaches of the C-6 canal show less of an impact with increasing mining as compared to the upstream reach. These downstream reaches drain less ground water during wet conditions than does the upstream reach, either with or without the proposed C-4/C-6 structures. However, under dry conditions, the downstream reaches of C-6 recharge the ground water (see figure 16). On the other hand, with the proposed structures in place, these canal reaches tend to drain rather than recharge ground water. In addition, the magnitudes of these base flows are much smaller under dry conditions than under wet conditions.

The water budgets for the C-2 Extension canal for wet conditions indicate that this canal behaves like a recharge canal, supplying the Northwest well field and the areas to the east. With additional mined lakes, the canal supplies less water to the wellfield since the effective increase in aquifer transmissivity reduces the drawdown cone from the wellfield. However, with the structure downstream of the C-4/C-2 intersection in place, the water budget under wet conditions shows that the canal drains rather than recharges the aquifer. This trend of decreasing recharge across scenarios is absent under dry conditions, where the water budgets indicate that the canal recharges the aquifer for all the three scenarios.

Base flows for the reaches of the C-4 canal located upstream of C-2 appear to be impacted to a lesser degree from the additional mining. These canal reaches drain the aquifer under steady state conditions and only a slight increase in ground water flow to the canal is seen with increased mining. However, with the proposed structures in place there is a reversal in the direction of the base flow and the canal recharges the aquifer. Additional water would need to be supplied by the regional system to maintain this condition. In contrast, the C-4 canal reaches located downstream of the C-2 confluence drain the aquifer for all the three scenarios under both dry and wet conditions, with significantly larger quantities of ground water flowing into the canal with the structures in place.

The water budgets for the L-31N borrow canal between the C-4 confluence and the proposed structure indicate that, under wet conditions, the canal drains less water as mining is increased due to the increase in effective aquifer transmissivity and, consequently, easterly ground water flow in the aquifer. This will reduce the amount of water available in L-31N further downstream. Furthermore, it appears that when the proposed structures are added and the upstream stages are maintained at the desired elevation, base flow to the canal is nearly eliminated. This would result in an increase in water supply for areas located east of the mining area. On the other hand, during dry annual hydrologic conditions, figure 16 indicates that L-31N recharges the aquifer under all three scenarios and that the increase in mining alone would, under the steady state conditions investigated, result in approximately 13,000 acre feet per year of additional water having to be supplied from the regional system in order to maintain the canal stage. With the structures in place, however, losses from L-31N under dry annual hydrologic conditions would be reduced to a rate that is less than that which occurred prior to the additional mining and structural improvements. As indicated previously, this would require that additional water from the regional system be supplied to the upstream reaches of the C-4 canal.

Changes in Ground Water Flows

In order to address the effects of the proposed mining plan on ground water supplies, total ground water flows across selected boundaries were quantified under both wet and dry annual hydrologic conditions. These boundaries include:

- the east boundary of WCA-3B along L-30;
- the east boundary of the Pennsuco wetlands along the D-B levee;
- the east boundary of the Lake Belt located along the C-2 Extension canal between C-6 and C-4.

Changes in ground water flows across each of these boundaries are explained below.

Ground Water Flow from WCA-3B

Under wet annual hydrologic conditions, it is apparent from figure 15 that increases in seepage rates from WCA-3B will be small under the proposed mining scenario and will decrease about 20 per cent if the structures are added to the proposed mining plan. Similar effects on WCA-3B can be seen under dry annual hydrologic conditions. However, *it is important to realize that these results are based on the assumption that no changes occur across scenarios in the L-30 borrow canal stages. For this assumption to hold under conditions of increased mining, additional water will have to be supplied from the regional system.* In fact, the results shown in figure 15 indicate that, for increased mining and no structural improvements, approximately 12,000 acre feet per year of additional water during wet annual hydrologic conditions would be needed to maintain the L-30 borrow canal stage while an increase of about half that amount would be needed under dry annual hydrologic conditions. On the other hand, with the proposed structures in place, the results suggest that substantially less water will need to be delivered to the L-30 borrow canal provided that the required deliveries to the C-6 canal can be made.

Easterly Ground Water Flow Underneath the Dade-Broward Levee

According to figures 15 and 16, increasing mining from the permitted to proposed footprint with no structural improvements will result in an increase in easterly ground water flow past the Dade-Broward levee of about 14,000 acre feet per year during wet annual hydrologic conditions and about 9500 acre feet per year during dry annual hydrologic conditions. These increases are primarily due to the larger area of influence of the Northwest wellfield resulting from the additional quarries. With the proposed structures in place, these increases in ground water flow become 23,000 and 10,000 acre feet per year, respectively, due to the higher water levels in the Pennsuco wetlands.

Easterly Ground Water Flow Past the Lake Belt

Figure 15 indicates that under wet annual hydrologic conditions, the change in easterly ground water flow past the turnpike between C-6 and C-4 will be negligible under the proposed quarry configuration, but will increase significantly with the new structures in place. Much of this increase in flow occurs south of Structure J in the C-2 Extension canal and some of it flows back into the C-2 Extension canal at locations north of Structure J. Similar conclusions can be drawn for dry annual hydrologic conditions but, in this case, the C-2 extension canal primarily recharges the aquifer in all three scenarios.

Conclusions

Based on the above evaluation of the proposed mining plan along with its associated structural improvements, it is apparent that unless the structural improvements are implemented, decreases in average annual surface water levels within the Pennsuco wetlands may occur under wet annual hydrologic conditions. However, it is apparent that water levels within certain portions of the Pennsuco wetlands may still be impacted despite these improvements. Similar statements can be made regarding ground water levels in this area under wet or dry annual hydrologic conditions.

The increased mining may result in higher ground water levels in the Lake Belt mining area. These increases will be greater if the proposed structural improvements are implemented, and will spread to parts of the surrounding urban areas. While this may pose as a water supply benefit during dry hydrologic conditions, it may result in a greater flooding potential as well as undesirable impacts to local infrastructure during wet conditions.

Maintaining the desired canal stages associated with the proposed structural improvements will require additional water from the regional system. In addition, the proposed structural improvements may, in certain cases, result in significant changes to downstream canal flows. The consequences of this should be investigated. In addition, further analysis may reveal that slight modifications to the proposed structure configuration will be necessary.

It should be emphasized that the results presented here are based on the current version of the Lake Belt ground water flow model. Refinements to the model's calibration will be carried out in the near future, which could lead to changes in the results. In addition, there are uncertainties in the results presented here due to uncertainties inherent to the model itself. The effects of model uncertainty on these results should be investigated prior to making any final decisions regarding future mining plans.

Hydrologic Analysis of Limestone Mining South of Tamiami Trail Between Krome Avenue and the L-31N Canal

Prepared for the Lake Belt Advisory Team
To the
South Florida Ecosystem Restoration Working Group

April 24, 1997

Acknowledgements

This work was undertaken in an attempt to provide the Lake Belt Issue Advisory Team with hydrologic information related to continued mining in Sections 24 and 25, south of Tamiami Trail between Krome Avenue and the L-31N Canal. The work was performed by the consulting firm of MacVicar, Federico & Lamb, Inc on behalf of the landowner, Kendall Properties and Investments

The analysis was made possible by the gracious sharing of computer models and related data files by the staff of the South Florida Water Management District. The work was performed using a comprehensive Modflow model of the hydrologic system of Dade County, developed at the District by Mark Wilsnack and Sashi Nair under the supervision of Jayantha Obeysekera

Executive Summary

The hydrology of the area south of Tamiami Trail, west of Krome Avenue is dominated by the L-31N Canal Constructed originally to provide material for the adjacent levee, the canal was greatly enlarged in the late 1970s as a central component of the South Dade Conveyance System This project was constructed to facilitate the transfer of water from Lake Okeechobee to the southeast corner of Everglades National Park south of Florida City The canal cuts through an area of extremely high groundwater flow, most of which originates from the Everglades National Park (ENP) expansion area (**Figure 1**) The hydrologic restoration of this area, known as Northeast Shark River Slough (NESRS), is one of the highest priority objectives of the broader Everglades Restoration initiative

During the wet season the L-31N canal intercepts groundwater flow from Water Conservation Area 3B and ENP and conveys it to the C-111 basin in south Dade During dry conditions water from Lake Okeechobee is introduced into the canal to recharge the Biscayne aquifer The analysis summarized in this report shows that raising the water elevation in the northern reach of the L-31 canal could significantly reduce the amount of water now seeping out of Everglades National Park and WCA-3B

The key to improving water conditions in this area, especially for the Everglades, is controlling the seepage quantities now leaving the Park in a way that both minimizes the total amount of flow and returns as much of this flow as possible to the Park

Based on the model results, increasing the size of the existing quarries in sections 24 and 25 within the areas analyzed for this report would have virtually no impact on seepage from the west under most conditions and only minimal effect (less than 2 0 %) during very dry conditions

During wet conditions the larger quarries would slightly increase goundwater flow to the east of the canal and slightly decrease the amount of flow diverted to south Dade by the L-31N canal During very dry conditions larger quarries would increase goundwater flow to the east Under these conditions the L-31N canal is functioning to provide recharge to the aquifer and the increased groundwater flow, although minor, may be a benefit to nearby wellfields

Background

The Lake Belt Issue Advisory Committee created by the South Florida Ecosystem Restoration Working Group is reviewing the issues associated with limestone mining within the Lake Belt Region designated by the Florida Legislature This report summarizes a computer modeling evaluation of mining scenarios for the area south of Tamiami Trail between Krome Avenue and the L-31N Canal

This area of Dade County has been the subject of extensive hydrologic monitoring over the last fifteen years because of the focus on the restoration of sheet flow to Northeast Shark River Slough, located just west of the L-31N canal The construction and operation of the South Dade Conveyance System, completed in 1982, has resulted in dramatic changes to the hydrology of Dade County south of Tamiami Trail Large quantities of water are diverted from NESRS and WCA-3B by the L-31N Canal and conveyed into the canal system to the south This has had negative environmental consequences in the Everglades and Florida Bay and contributed to flooding problems for agricultural land uses

Figure 2 summarizes rainfall and canal flow data for the L-31N canal since 1968. The dramatic increase in flow to the south beginning in 1983 is well documented in the flow data collected by the Water Management District. **Figure 3** is a diagram of the water budget for this area for 1993. Several important trends are evident from the 1993 data:

1. Seepage losses from NESRS, which take water away from a critical area of Everglades National Park, are substantial, and
2. The L-31N Canal is the dominant transport feature, conveying this water to the C-111 canal in south Dade.

In 1989 Congress approved the addition of Northeast Shark River Slough to Everglades National Park and at the same time authorized the Modified Water Deliveries Project to reflood that area of the Everglades. The facilities necessary to redirect the flow in L-31N back into Everglades National Park are critical components of this plan.

The sensitivity of this area to changes in hydrology and the serious problems that already exist led the Advisory Team to request additional analysis of continued limestone mining in this area.

Methodology

The Water Management District's Dade County Modflow model, used in previous analyses related to the Lake Belt, was utilized to estimate the steady state flow rates for various configurations of limestone quarries, L-31N canal stages and possible step-down structures in the L-31N canal.

Two parameters in the model were adjusted to reflect the hydrologic interactions between groundwater flow and the L-31N canal. The conductance term for the L-31N canal was modified to agree with the value published by the USGS (96-4118). The conductance associated with the general head boundary in Northeast Shark River Slough (NESRS) and WCA-3B were increased to reflect that those areas are inundated by surface water during wet conditions.

In order to isolate the impacts of the canal, the quarries and water levels in the Park, a model configuration as shown in **Figure 4** was used. The Park cells were used as general head boundaries to the west of the cells containing the L-31N canal. The Canal was simulated with a constant stage. Lakes were modeled as in the previous Lake Belt analysis by using an extremely high transmissivity value for the top 80 feet in each model cell that was defined as a lake. In this evaluation quarries were always simulated as encompassing an entire grid cell. The 1500 foot buffer was modeled with one full cell between the quarry cells and the cells containing the L-31N Canal. The 2000 foot buffer was simulated using a varying buffer width from 1500 to 2500 feet such that the average distance from the canal was 2000 feet and the total acres of mines matched the proposal by the landowners.

Wet conditions were modeled based on the 1969 data set developed by the District with rainfall recharge adjusted to reflect the 1993 wet season. Dry conditions were modeled using the 1989 data set. Two L-31N canal stages upstream of G-211 were evaluated for the wet condition, 5.75 and 5.25 feet. The higher number represents the average level now maintained by the District. The lower level represents a level that was used prior to the construction to G-211 and also the level used in the original design of the Modified Water Deliveries Project. The dry condition level in the canal was set at 4.79 feet.

Results

The information related to this evaluation was derived by computing the water budget for the model cells containing the L-31N canal (see **Figure 3**). The primary environmental issue is the volume of seepage leaving WCA-3B and ENP due to groundwater flow to the east. The groundwater flow intercepted by the canal is also important because, under present operations, it is diverted out of the Shark River Slough watershed and into south Dade where it contributes to problems affecting agriculture and Florida Bay.

Under dry conditions the canal acts as a recharge feature supplying water to Dade County. This dry season supplemental water represents a demand on the regional water management system and is the design objective of the South Dade Conveyance System. **Figure 5** shows the study area and the various flow sections for both groundwater and canal flow used in this analysis.

THE IMPACTS OF CONTINUED MINING. **Figure 6** displays the estimated flow quantities for the various flow sections under both wet and dry conditions. Several conclusions can be drawn from the results.

1. The wet season impact of the L-31N Canal is very significant. Roughly 70% of the seepage leaving ENP and WCA-3B is intercepted by the canal. The need to reduce the seepage amount is apparent. Implementing a plan to return the water that is captured back to the Park is also important and is part of the Modified Water Deliveries Plan.
2. The extent of new mining reviewed for this study has very minimal effect on the total amount of water leaving the Park. The quarries do allow more groundwater flow to the east. Under most conditions this increase in flow is offset by an equivalent reduction in flow to the south from the L-31N canal.
3. During very dry conditions the quarries exert a slightly larger influence on the flow to the east. This could require more water from the north to provide recharge to the canal.

NEW STRUCTURES IN L-31N. To address the impact of the L-31N canal a step-down structure in the canal was simulated at two separate locations. A new structure was modeled at both two miles and four miles south of Tamiami Trail. In both cases the headwater of the new structure was set at 6.5 ft. (an increase of 0.75 ft above the canal level south of the structure) in the wet season and 4.9 ft. (a 0.1 ft increase) in the dry season. **Figure 7** shows the effect of the structure on each flow section.

Significant reductions in seepage from the Park and WCA-3B are evident under both wet and dry conditions. A major wet condition improvement is also noticed in the reduction of flow volume intercepted by the canal. The price for these improvements in the wet season is a slight increase in flow to the east and potentially higher stages on property east of the canal. Under dry conditions the higher stage upstream of the structure results in more seepage to the east from the canal.

Figure 8 shows two data summaries that reinforce the importance of the L-31N canal. The first is a simple sum of the four flow quantities that have been analyzed with the modflow model.

Changes to the canal operations, either by changing the control level in the entire canal or by building a step-down structure, are very effective in reducing the total amount of unwanted groundwater flow. The three mining scenarios tested have virtually no impact on the total flow amount. The second graph is a plot of the actual daily water budget for L-31N canal from 1988 through 1991. That reach of the canal is rarely inactive. It is almost always acting in either the drainage or recharge mode, which points out the importance of resolving the final design and operation of that feature in the Modified Water deliveries Project.

SENSITIVITY ANALYSIS. In addition to looking at mining configurations and new structures the model was run to quantify the effect of the L-31N canal stage and of holding much higher stages in the Park corresponding to those predicted by the Natural System Model. As expected (**Figure 9**) a lower operating level in L-31N induces more flow from the Everglades and results in higher flow rates in the canal. The 5.25 ft. level was simulated because it is close to the level used before G-211 was constructed and it also corresponds to the operating level specified in the Modified Water Deliveries Plan. Under that plan flow from the canal would be pumped back into the Park at Tamiami Trail.

Since the L-31N canal is such a dominant feature of the area, and hence of the computer model used in this analysis, care was taken to check the validity of the flow data for the canal computed by the model. The conductance term in Modflow determines the interaction between the canal and the surrounding aquifer. The value taken directly from the USGS report on their investigation of this canal produced flow rates comparable reported in the District's data base for flow through G-211 and S-338 for similar hydrologic conditions. This conductance value, roughly 0.119 cubic feet per second / per foot of head difference between the canal and the groundwater / per foot of canal length, is quite high. To check the reasonableness of the conclusions the model was run with a value equal to one fourth of that. **Figure 10** shows the results under both wet and dry conditions. While the quantities of flow in L-31N are reduced as would be expected, the overall conclusions with respect to the impacts of continued mining due not change.

Conclusions

This study looked at the issues affecting the water budget in that section of the Lake Belt south of Tamiami Trail. While the main focus is on the extent of mining that should be considered by the Issue Advisory Team, other important factors affecting water flow were also considered.

The computer modeling was limited to steady-state analyses of a wet and a dry condition. In both cases the results document the large loss of groundwater from the Everglades directly related to the design and operation of the L-31N Canal. Large reductions in this water loss appear to be achievable with the construction of an additional structure, similar to G-211, in the canal. The impacts of continued mining in sections 24 and 25 are also documented. The quarries appear to have no significant impact on Everglades National Park under wet or dry conditions. However they do result in an increase in groundwater flow to the east. This may be beneficial to Dade county water supplies in the dry season due to the location of several major wellfields to the east of the L-31N canal.

Analysis of Seepage and Hydroperiod Impacts of the Lake Belt Plan

(Based on the October 1997 Lake Belt Model Developed by the SFWMD)

Approach

Steady-state and transient simulations were made to evaluate the seepage and hydroperiod impacts of the Lake Belt Plan. Steady-state scenarios were designed to bracket extreme wet and dry hydrologic conditions. The wet condition was represented by the average of June 1 to November 30 of 1969, while the dry condition was represented by January 1 to May 31 of 1989. Transient model runs include the 1968-69 and 1988-89 scenarios. To eliminate the impacts of initial conditions, each simulation covers two years and only the results of the second year are presented. The sensitivity of the model results to conductivity values used for the Pennsuco wetlands was also examined for the wet 1968-69 transient run. 165 and 15 MGD pumpages were used for the Northwest and West wellfields, respectively.

Seepage Impacts - Central Lake Belt

Based on steady-state simulations, the Issue Team Plan (see sketch), when complete, would result in a 5% (16 cfs) increase in seepage from WCA-3B during the wet period, and a 4% (9 cfs) increase during the dry period when compared to mining only the permitted lakes. Adding a water control structure in the wellfield protection canal would mitigate for these impacts and reduce the seepage by 4% (-14 cfs) during the wet period, and reduce the seepage slightly (<1%) during the dry period. Reducing seepage from WCA-3B during the extreme dry conditions would require additional water from the regional system (presumably Lake Okeechobee). The amount may vary from 10 to 60 cfs (see the canal leakage table). As also shown in the water budget tables, transient simulations produce seepage results comparable to the steady-state runs. Daily seepage from WCA-3B and the ENP simulated using transient runs are presented in the attached figures.

Seepage Impacts - Kendall Properties (Krome Quarry)

Based on steady-state model runs, mining the entire Krome Quarry tract (see sketch) would result in a 2% (4 cfs) increase in seepage from the ENP during the wet period, and a 11% (3 cfs) increase during the dry period compared to mining only the permitted lakes. Adding a structure in the L-31N canal would reduce the seepage by 8% (-18 cfs) in the wet period and 11% (-3 cfs) in the dry period compared to the permitted lakes. Reducing the seepage from the ENP during a severe drought would require an estimated 15 cfs additional water from the regional system (see the canal leakage table). The transient simulations produce seepage results comparable to the steady-state model runs.

Hydroperiod Impacts in the Pennsuco Wetlands

Impacts on hydroperiod in the Pennsuco wetlands were examined using transient simulations. As shown in the plots of daily water level in the Pennsuco wetlands, mining impacts on hydroperiod during the drought year are not significant. The most severe impacts are found in the extreme wet period when persistent ponding occurs in the wetlands.

The Issue Team Plan would result in an average reduction of 35 days in hydroperiod in the Pennsuco wetlands. Adding structures in the wellfield protection canal and the C-4 canal would increase the average hydroperiod in the Pennsuco wetlands by 5 days (2%) compared to the permitted mining configuration.

Because the model does not explicitly simulate the surface water characteristics of the Pennsuco wetlands when it is inundated by employing a drastically greater hydraulic conductivity, the impacts on hydroperiod as predicted by the model are very uneven: more impacts occur on the east side of the wetlands which is closer to the new lakes and much less impacts are seen on the west side. These effects are shown in the attached plots with column 70 of the model grids representing the east side of the wetlands and column 63 representing the west side. In reality, one would not expect such a large difference within the Pennsuco wetlands during very wet periods.

Sensitivity of Hydroperiod Impacts to Pennsuco Wetlands Representation

Wetlands have been simulated using a ground water model and a very high hydraulic conductivity. Hydraulic conductivity values as high as 30,000,000 ft/day were used to represent the Shark River Slough by the USGS (1996). To examine the sensitivity of the model to a higher conductivity in the Pennsuco area, three test runs (1968-69) were made using 100,000, 5,000,000, and 30,000,000 ft/day as the hydraulic conductivity for the top model layer in the Pennsuco wetlands. The resulting average seepage from WCA-3B, as well as daily seepage and stage plots, are attached. The general impacts of the higher conductivity are: (a) more seepage from the WCA-3B (but the percent changes caused by additional mining and water control structures remain the same); and (b) more smoothed water table and hydroperiod changes within the Pennsuco wetlands; the impacts of additional lakes and water control structures on hydroperiod remain similar to the base model predictions with slightly less negative impact by additional lakes and more positive impacts by water control structures with the higher conductivity values.